A New Bioenergy Model that Simulates the Impacts of Plant-Microbial Interactions, Soil Carbon Protection, and Mechanistic Tillage on Soil Carbon Cycling

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Project Goals:

We developed a new model of soil carbon (C) in bioenergy systems that incorporates plant-microbe interactions, microbial physiology, and mechanisms of stable soil C creation and loss to test hypotheses on the response of soil C to bioenergy feedstock traits and environmental conditions. We then used the model to address the following questions:

(1) How do commonly used model representations of tillage vary in soil C projections as compared to a novel tillage mechanism that increases microbial access to soil C?

(2) How do differences between annual and perennial bioenergy feedstocks in their integrated plant-microbial traits and tillage regimes impact model estimates of soil C?

(3) To what extent do these model differences in the representation of feedstock traits alter the response of soil C estimates to warming temperatures?

(4) Does the outcome of altering plant traits (i.e., increased rhizosphere C exudation) on model estimates of soil C vary across different feedstocks?

Advancing our predictive understanding of bioenergy systems is critical to designing decision tools that can inform which feedstock to plant, where to plant it, and how to manage its production to provide both energy and ecosystem carbon (C) benefits. Here, we lay the foundation for that advancement by integrating recent developments in the science of belowground processes in shaping the C cycle into a new bioenergy model, FUN-BioCROP (Fixation and Uptake of Nitrogen-Bioenergy Carbon, Rhizosphere, Organisms, and Protection). We show that FUN-BioCROP can approximate the historical trajectory of soil C dynamics as natural ecosystems were successively converted into intensive agriculture and bioenergy systems. This ability relies in part on a novel tillage representation that mechanistically models tillage as a process that increases microbial access to C. Importantly, the impacts of tillage and feedstock choice extend into FUN-BioCROP simulations of warming responses with no-till perennial feedstocks, miscanthus and switchgrass, having more C that is unprotected and susceptible to warming than tilled annual feedstocks like corn-corn-soybean (Fig. 1). However, this susceptibility to warming is balanced by a greater potential for increases in belowground C allocation to enhance soil C stocks in perennial systems. Collectively, our model results highlight the importance of belowground processes in evaluating the ecosystem C benefits of bioenergy production.

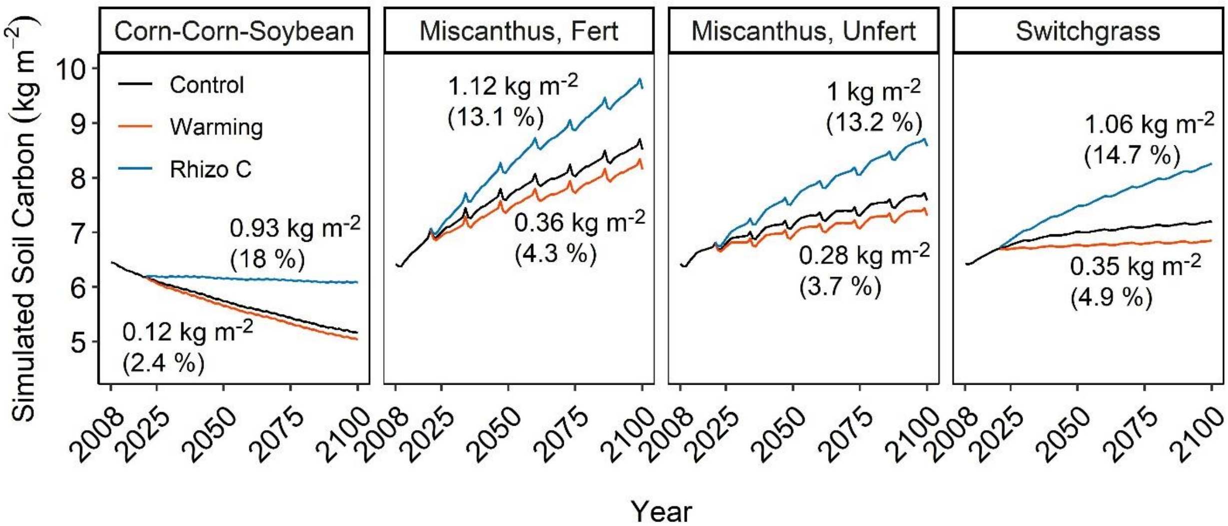

Figure 1. Total soil carbon (C) simulated by FUN-BioCROP at the University of Illinois at Urbana-Champaign Energy Farm under three sets of experimental conditions: control (black lines; same data as shown in Figure 3), 5 °C soil warming (red lines), and increased rhizosphere C flux ("Rhizo C;" blue lines; augmented mycorrhizal C flux and non-mycorrhizal root C exudates by 5% of average daily NPP). Values on the figure indicate the difference between each experimental (i.e., warming, or increased rhizosphere C) final C pool value as compared to control, with the percent difference in parentheses. E.g., increased rhizosphere C in corn-corn-soybean led to 18% higher SOC at the end of the simulation. Fert- fertilized, Unfert- unfertilized, FUN-BioCROP- Fixation and Uptake of Nitrogen-Bioenergy Carbon, Rhizosphere, Organisms, and Protection.

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